Evaluation of Rectangular and Circular Escape Vents in the Northwestern Hawaiian Islands Lobster Fishery

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Abstract.—Research was conducted in Hawaii during 1984–1987 to investigate the possibility that escape vents fitted in traps used by the commercial lobster fishery in the northwestern Hawaiian Islands would reduce the catch and mortality of sublegal spiny lobsters *Panulirus marginatus* (<50 mm tail width) and slipper lobsters *Scyllarides* spp. (<56 mm tail width) without significantly reducing legal catch. A circular vent was more efficient than the traditional rectangular vent in maximizing escapement of sublegal lobsters and retention of legal ones for both species. Optimum results were attained with two vented panels each containing four 67-mm-diameter circular vents. Traps equipped with the circular vents caught 83% fewer sublegal spiny lobsters and 93% fewer sublegal slipper lobsters than nonvented control traps, and they did not significantly reduce legal catch of either species. In contrast, traps with two 49-mm-high × 285-mm-wide rectangular vents reduced the catch of sublegal spiny and slipper lobsters by 70 and 93%, respectively, but also reduced legal slipper lobster retention by a significant 32% of the control catch. As a result of this research, all traps used in the lobster fishery in the northwestern Hawaiian Islands after 1 January 1988 must be equipped with two panels with 67-mm circular vents. The 1988 catch of sublegal spiny lobsters declined by 38% at Necker Island, northwestern Hawaiian Islands, whereas the legal catch increased substantially.

The mortality of sublegal lobsters (i.e., below minimum legal size) after they are trapped and released is a major problem in lobster fisheries throughout the world. Factors contributing to this mortality include direct physical damage caused by handling, displacement from home reefs, and increased predation resulting from weakened condition after release (Brown and Caputi 1986; Hunt and Lyons 1986; Lyons 1986). The problem is important because even low mortality can result in the loss of substantial revenue to a fishery when the loss of potential reproduction is added to the value of individual lobsters. Escape vents fitted onto the sides of traps have been used to reduce sublegal mortality in lobster fisheries in Canada (Wilder 1949), California (Lindberg 1955), Australia (Bowen 1963), New Zealand (Ritchie 1966), and New England (Krouse and Thomas 1975) and have been proposed for use in Florida (Lyons and Hunt, in press).

The present commercial lobster fishery in Hawaii is largely confined to a string of atolls and banks northwest of the island of Niihau and collectively referred to as the northwestern Hawaiian Islands (Figure 1). This fishery expanded rapidly after 1976, when a single vessel began trapping spiny lobsters *Panulirus marginatus* at Necker Island (Uchida and Tagami 1984). The fishery exploits *P. marginatus* and several species of slipper lobsters *Scyllarides* spp. *Scyllarides squammosus*

constitutes up to 90% of the slipper lobster catch (R. P. Clarke, P. A. Milone, and H. E. Witham, Southwest Fisheries Science Center, unpublished data). Hereafter, spiny and slipper lobsters will refer to *P. marginatus* and *S. squammosus*, respectively. Current regulations prohibit the harvest of spiny lobsters of less than 50 mm tail width (TW) and slipper lobster of less than 56 mm TW (Western Pacific Regional Fishery Management Council, 1985 and 1987, Honolulu, Hawaii). In 1986 nearly 900,000 legal spiny lobsters (521 tonnes) and about 1.4 million slipper lobsters (484 tonnes) with a combined ex-vessel value of US$6.0 million, were landed in the northwestern Hawaiian Islands (Clarke, Milone, and Witham, unpublished data), making this one of the most lucrative commercial fisheries in Hawaii. Total spiny lobster catch in 1986 was 1.4 million animals, 22.6% of which were sublegal and had to be released. No minimum-size limit was in effect for slipper lobsters prior to March 1987, but a substantial portion of the catch consisted of individuals below the current legal size.

The effect of vented traps on the escapement of sublegal spiny lobsters was initially addressed in Hawaii from 1979 to 1982 (Paul 1984). Early results proved promising, so research on escapement of sublegal spiny lobsters was continued during 1984 (Skillman et al. 1984). The ultimate goal of the present study was to develop an escape vent
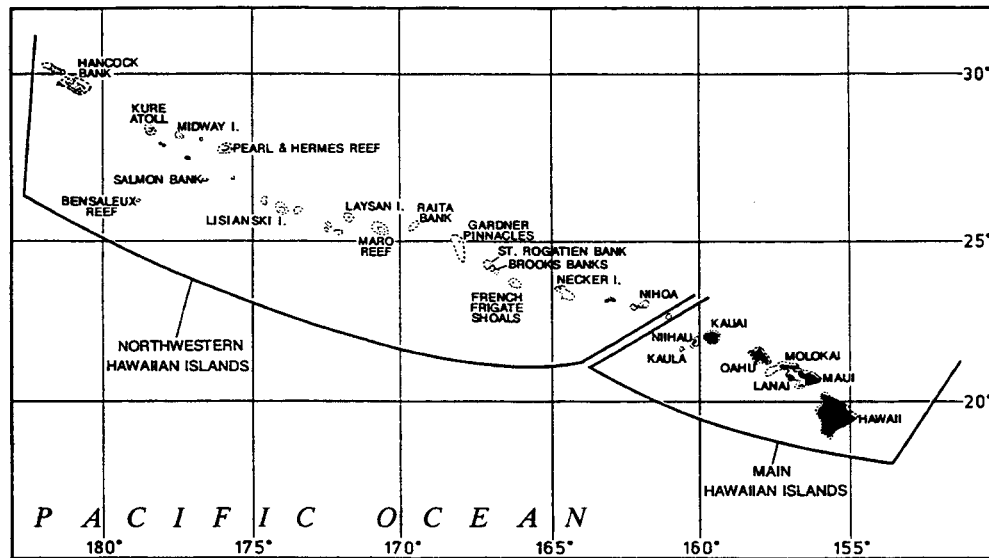
FIGURE 1.—The Hawaiian Archipelago.

that would allow sublegal lobsters of both major species to escape without significantly compromising legal catch.

Methods

The experimental design, originally proposed in March 1984 (Skillman et al. 1984), consisted of four research phases designed to determine the optimum escape vent size for spiny lobsters. In phase 1, the vent size was estimated by simply passing legal spiny lobsters through various-sized rectangular openings. In phase 2, this preliminary estimate was used to set up and conduct laboratory escapement trials based on a response surface model (Cochran and Cox 1957). During phase 3, these laboratory estimates of escape vent size were refined by conducting field trials aboard the National Oceanic and Atmospheric Administration ship *Townsend Cromwell* on the same fishing grounds used by the commercial fleet. In phase 4, the efficiency of the optimal vent design was tested on a commercial lobster vessel during normal trapping operations.

Modifications of the original experimental design were necessary because of changes in the fishery and its management while the experiment was being conducted. Beginning in 1983–1984, fishermen began replacing their old 50 × 100-mm wire-mesh traps with a new, smaller-mesh trap made of polyethylene, which led to an enormous increase in slipper lobster catch in 1984–1985. Because of the increasing importance of the slipper lobster catch, we modified our vent design in 1985. Carapace length (CL) of the lobster was measured prior to 1986 to determine legal size. A minimum tail-width criterion was established in October 1985 in response to the increasing practice by commercial fishermen of detaching tails and freezing them at sea. This conversion from CL to TW also dictated a change in vent size. For ease of presentation, measurements originally recorded in CL have been converted to TW by the functional linear regressions TW = 5.624 + 0.591CL (N = 1,354, r^2 = 0.866) for spiny lobsters and TW = −2.106 + 0.779CL (N = 1,655, r^2 = 0.953) for slipper lobsters. Several changes in the minimum-size regulation for spiny lobster that occurred during our study, plus the establishment of a minimum legal size for slipper lobster (June 1987), required us to test a wider range of vent sizes than originally planned.

Laboratory experiments.—Gear selectivity studies with spiny lobsters (Bowen 1963; Paul 1984) indicated that a rectangular vent 285 mm wide and 54–60 mm high would be the optimal starting point for phase 1. Initially, at least five live spiny lobsters in each 1-mm size-class from 49 to 52 mm TW were obtained from commercial fishermen. The tips on the pleura of the abdominal tail segments were clipped in a predetermined pat-

tern to allow rapid identification of each size-class. These animals were passed through Plexiglas[1] vents with vertical dimensions of 54, 56, and 58 mm, and total escapement of each size-class was compared for all three vent sizes. The same experimental procedure was later used to determine the initial optimal circular-vent sizes for spiny and slipper lobsters.

Laboratory escapement trials were conducted in a U-shaped concrete enclosure with flowing seawater maintained at a depth of approximately 1 m. The tank was subdivided with wire mesh, and each test section was covered with a panel composed of heavy greenhouse shading material to protect the animals from the blinding effects of the sun (Phillips et al. 1980). In addition, concrete blocks provided shelter for the animals as they left a trap.

The Fathoms Plus shellfish trap, which by 1984 had almost completely replaced the wire-mesh trap originally used in the fishery (Figure 2), was used in laboratory trials. This dome-shaped, single-chambered trap is molded of black polyethylene, measures 980 × 770 × 295 mm, and has a mesh size of 45 × 45 mm (inside dimensions). Each trap has two entrance cones located on opposite sides.

The rectangular-vent panel was originally manufactured out of 18-gauge (1.3 mm) sheet aluminum. Thickness was increased to 11 gauge (3.2 mm) soon after the trials began, when it was discovered that the animals could pry their way out of the thinner models by bending the sides of the vent. Two vents, 285 mm wide and attached on opposite sides of the trap, were used in all trials, although their height and placement varied.

Laboratory trials (phase 2) in May 1984 tested vents with heights of 54, 55, and 56 mm, based on a legal size of 51 mm TW for spiny lobsters. These vents were placed on the sides of the traps 45 mm from the bottom (LOC I). To determine the effect of vent location on escapement of slipper lobsters, additional laboratory trials in June 1985 tested 55-mm vents placed at three other positions on the trap: 115 mm from the bottom (LOC II), 195 mm from the bottom (LOC III), and on the top of the trap (LOC IV) (Figure 2). A fourth trap, with vents placed at LOC I, served as a control. Reduction in minimum legal size of spiny lobsters to 47 mm TW prompted the repetition of the procedure in September 1985 with either 50- or 51-mm vents placed at LOC III.

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[1] Reference to trade names does not imply endorsement by the U.S. National Marine Fisheries Service.
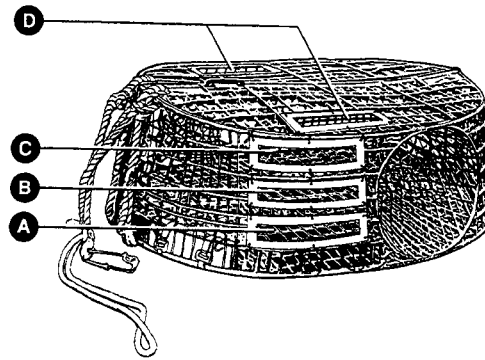

FIGURE 2.—Fathoms Plus shellfish trap, showing vertical placement of escape vents used to test for differences in escape rate: (A) 45 mm from bottom (LOC I); (B) 115 mm from bottom (LOC II); (C) 195 mm from bottom (LOC III); (D) top of trap (LOC IV).

Laboratory trials were conducted in March 1986 to compare escapement from circular and from rectangular vents for both species. In addition square vents were tested. The trials used three spiny lobsters in each 1-mm size-class from 47 to 52 mm TW and three slipper lobsters in each 5-mm size-class from 45 to 60 mm TW. All vents were placed at LOC I and on opposite sides; their sizes were as follows: (1) two rectangular (53 × 285-mm) vents (control); (2) two vent plates each containing three squarish (55 × 68-mm) vents placed in a row 25 mm apart; (3) two vent plates each containing three circular vents (70 mm in diameter) placed in a row about 25 mm apart.

Research vessel experiments. Initial in situ trials (phase 3) were conducted aboard the *Townsend Cromwell* over 13 d in June and October 1984. The traps used in the trials had two rectangular vents (12-gauge sheet aluminum) 54, 55, or 56 mm high. Six strings, with 10 traps per string, were set at various locations around Necker Island (June, October) and Maro Reef (October) at depths of 30–60 m. Each of the three vent sizes was fished on separate strings, and each string contained five vented traps alternated with five nonvented traps. Each trap was baited with chub mackerel *Scomber japonicus* and set shortly before sunset. Traps were hauled after 0800 hours the following morning, and all lobsters caught were weighed to the nearest 0.01 kg, measured (CL in mm), and sexed. Similar trials were conducted at the same locations in November 1985 to evaluate the effect of vent location on slipper lobster escapement. The same basic string configuration was used, except only 51 ×

285-mm rectangular vents were tested. Nine strings of 12 traps each were set per day. The traps were arranged on the string in triplets that alternated traps with vents placed at LOC I, control traps (nonvented), and traps with vents at LOC III.

Commercial vessel experiments.—Commercial trials (phase 4) conducted aboard the fishing vessel *Shaman* from August to November 1986 compared the efficiencies of rectangular and circular vents in releasing sublegal slipper and spiny lobsters. Four rectangular (heights, 43, 45, 47, and 49 mm) and four circular (diameters, 60, 62, 65, and 67 mm) vent sizes were selected to provide a range of retention sizes that covered the 1986 50-mm TW minimum-size limit for spiny lobsters and the proposed 52–56-mm TW minimum-size limits for slipper lobsters. All panels were manufactured of 12-gauge aluminum plate cut into 335 × 113-mm rectangles. The circular vent consisted of four equal-sized holes spaced evenly across the panel (Figure 3) and mounted at LOC I, whereas the rectangular panel had the same configuration as previous models mounted at LOC III. All traps had a mesh size of 16 × 45 mm, a size reduction instituted by the manufacturer in 1986.

The *Shaman* typically set 6–12 strings with 50–200 traps per string, for a total of 1,100 traps/d. Experimental traps were arranged on the string as triplets spaced 50 m apart and consisting of a rectangular vented trap, a nonvented control trap, and a circular vented trap. Theoretically, this modified experimental design would reduce much of the variation in catch per trap along the string and between traps on different strings that might occur during commercial trapping operations. To facil-

itate comparison of catch rates of the two vent types with similar retention sizes, the smallest rectangular (43-mm) and smallest circular (60-mm) vents were fished in the same triplet, followed by consecutively larger vents of both configurations. Fishing effort with these traps totaled 1,800 trap-nights at Maro Reef, Gardner Pinnacles, Raita Bank, and Brooks Bank (Figure 1). Fishing effort was measured by comparing catch per unit effort (CPUE) defined as catch per trap-night. Typical soak times for the research vessel and commercial fishery trials averaged 12–15 h/d.

Results

Laboratory Experiments

Phase 1 laboratory trials established that 54-, 55-, and 56-mm rectangular vent heights were of the optimum range to allow escapement of sublegal (<77 mm CL) spiny lobsters. A second-degree response-surface model based on Andrew's sine robust procedure was applied:

$$ER = [\sin(b_0 + b_1CL^2 + b_2VS^2 + b_3CL \cdot VS)]^2;$$

ER = escapement rate,
b_0 = −1.39564,
b_1 = 0.0209091,
b_2 = 0.0446067,
b_3 = −0.0607644,
CL = carapace length (mm),
VS = vent size (mm, vertical).

This model provided the best estimate of the parameter values and the rates of escapement at different vent sizes. Estimated escapement rates were calculated from the response-surface formula based upon results of phase 2 (Figure 4).

The phase 2 laboratory trials in June 1985 demonstrated that a rectangular vent 55 mm high placed at LOC III was most effective in deterring slipper lobster escapement without greatly influencing the escape of spiny lobster. The rate of slipper lobster escapement for this vent position, averaged over five trials, was 51% of the total number of slipper lobsters tested, compared with 85–98% for the other three vent positions. Similar results were obtained for spiny lobsters at the reduced minimum legal size of 47 mm TW.

The final set of laboratory trials suggested that, when circular vents 70 mm in diameter were used, escapement was similar for sublegal lobsters of both species. Total slipper lobster escapement was highest in traps fitted with a rectangular control vent and lowest in traps with circular vents. A similar number of spiny lobsters escaped from both
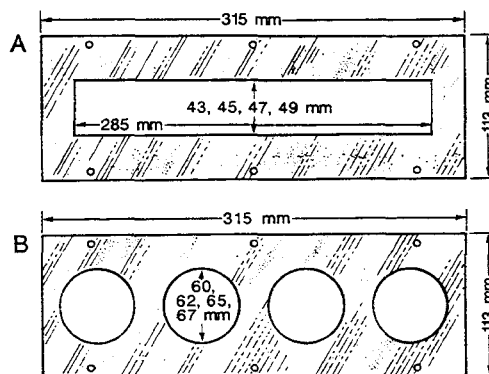
FIGURE 3.—Escape vent panels used during trials conducted aboard the commercial fishing vessel *Shaman*. (A) rectangular vent; (B) circular vents.
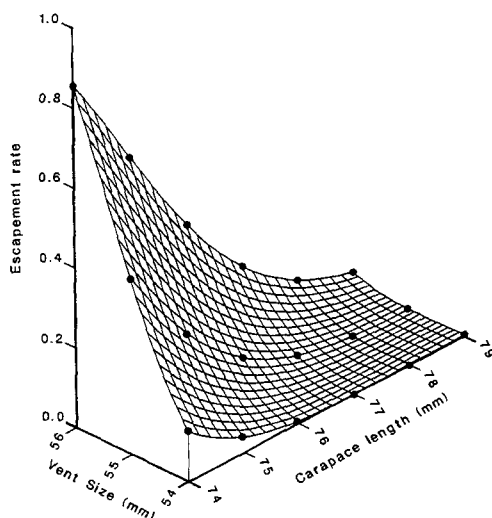
FIGURE 4.—Estimated escapement rate (expressed as a proportion) by rectangular vent size (vertical dimension) and carapace length for the initial spiny lobster laboratory trials in May 1984. Observed data points are indicated by black dots.

of these trap types. Square vents allowed escapement similar to that of circular vents for slipper lobsters from 53 to 56 mm TW; however, larger slipper lobsters continued to escape through the square vents by turning sideways and maneuvering through the square opening. Circular vents prevented this from occurring, indicating they could

be used to select for specific sizes of slipper lobsters based upon carapace width.

Research Vessel Experiments

The first series of in situ trials in June 1984 at Necker Island demonstrated that a 55-mm rectangular vent was most effective in allowing sublegal (<51 mm TW) spiny lobster escapement without negatively affecting legal catch. Catches of legal spiny lobsters increased in traps fitted with vents (Table 1). Mean legal CPUE was highest, and sublegal CPUE was lowest, for spiny lobsters in traps equipped with 55-mm vents during trials in June and October 1984. In addition, the mean difference in CPUE of legal spiny lobsters in June 1984 was significantly higher for vented than for control traps (paired t-test, P < 0.05).

Retention curves comparing cumulative percentage of total catch with TW for June 1984 showed a decrease in catch of sublegal spiny lobsters for all three vented traps (Figure 5). Vented traps also tended to catch larger animals than control traps (Figure 5). Sublegal spiny lobsters equaled nearly 80% of the catch in control traps but less than 20% in each vented trap. Differences in sublegal catches between control and vented traps were not as pronounced in October 1984 (Table 1) because of reductions in catch rates due to rough seas and poor weather conditions. However, despite poor catch rates, retention of sublegal spiny lobsters was reduced without significant escapement of legal animals.

TABLE 1.—Spiny lobsters: mean catch per unit effort (CPUE in trap hauls), standard error (SE), and mean difference in CPUE between rectangular-vented (V) and control (Con) traps (nonvented) during *Townsend Cromwell* cruises conducted in 1984 and 1985 for legal (≥51 mm tail width) and sublegal spiny lobsters. N = number of trap pairs (June and October 1984) or number of triplets (November 1985). For paired t-tests, asterisks denote P < 0.05* or P ≤ 0.01**.

Vent size (mm)[a]	N	Legal CPUE			Sublegal CPUE		
		V (SE)	Con (SE)	V − Con (SE)	V (SE)	Con (SE)	V − Con (SE)
				June 1984			
54	77	1.54 (0.17)	1.12 (0.15)	0.42 (0.17)*	0.26 (0.06)	3.21 (0.56)	−2.95 (0.54)**
55	76	1.94 (0.23)	1.40 (0.21)	0.54 (0.25)*	0.14 (0.04)	3.40 (0.58)	−3.26 (0.58)**
56	80	1.27 (0.19)	1.01 (0.13)	0.26 (0.16)	0.25 (0.06)	3.28 (0.45)	−3.13 (0.44)**
				October 1984			
54	170	0.82 (0.13)	0.88 (0.15)	−0.05 (0.11)	0.16 (0.03)	0.99 (0.23)	−0.84 (0.23)**
55	170	1.01 (0.14)	1.13 (0.20)	−0.12 (0.13)	0.03 (0.02)	0.93 (0.20)	−0.90 (0.19)**
56	170	0.94 (0.15)	1.08 (0.17)	−0.14 (0.14)	0.10 (0.04)	0.97 (0.21)	−0.87 (0.21)**
				November 1985			
51[b]	393	2.54 (0.24)	2.20 (0.21)	0.34 (0.14)*	1.34 (0.19)	3.63 (0.50)	−2.29 (0.34)**
51[c]	392	2.59 (0.25)	2.18 (0.21)	0.41 (0.15)**	1.55 (0.21)	3.59 (0.50)	−2.04 (0.32)**

[a] Vertical dimension.
[b] LOC I: vent located 45 mm from bottom of trap.
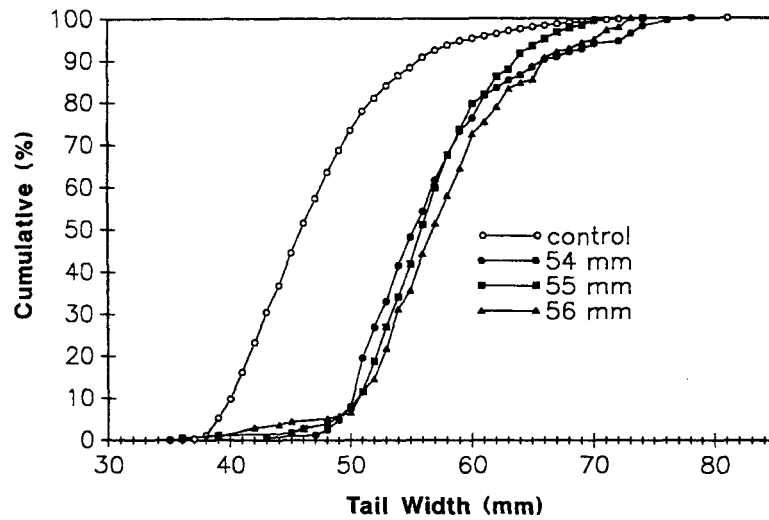[c] LOC III: vent located 195 mm from bottom of trap.

FIGURE 5.—Retention curves comparing cumulative percentage of total spiny lobster catch for rectangular-vented (54, 55, and 56 mm, vertical dimension) and control (unvented) traps tested in June 1984.

Field trials in November 1985 established that traps with 51-mm rectangular vents caught 50% more slipper lobsters when vents were at LOC III than when they were at LOC I (Table 2). However, the control trap without a vent outfished the LOC III trap by nearly 2.5 times for slipper lobsters larger than 50 mm TW (Table 2). Size-frequency distribution of slipper lobsters (LOC I: mean TW = 63.0 mm, SD = 4.50; LOC III: mean TW = 62.7 mm, SD = 5.24) was not significantly different for either vent location (Kolmogorov–Smirnov test, D_{max} = 0.0765, P > 0.05). Catches of legal and sublegal spiny lobsters were similar for both vent locations (Table 1).

Commercial Vessel Experiments

Commercial trials aboard the *Shaman* suggested little difference in catch (mean difference in CPUE) of legal (≥ 50 mm TW) spiny lobsters between the vented (rectangular and circular) and control traps for the three smallest vent pairs tested (Table 3). However, traps fitted with the largest rectangular vents (49 mm) caught significantly greater numbers of legal spiny lobsters than the control traps (paired t-test, P < 0.05).

The relative catch of sublegal spiny lobsters, expressed as the mean difference in CPUE of vented traps minus the mean CPUE of the control traps,

TABLE 2.—Slipper lobsters: mean catch per unit effort (CPUE in trap hauls), standard error (SE), and mean difference in CPUE between rectangular-vented (V) and control (Con) traps (unvented) during *Townsend Cromwell* cruises in June 1984 and November 1985. N = number of trap pairs (June 1984) or number of triplets (November 1985). LOC I = vent located 45 mm from bottom of trap; LOC III = vent located 195 mm from bottom of trap. For paired t-tests, asterisks denote P < 0.01**.

Vent size (mm)[a]	N	Mean CPUE		
		V (SE)	Con (SE)	V − Con (SE)
June 1984				
54	77	0.63 (0.14)	2.89 (0.23)	−2.26 (0.40)**
55	76	0.34 (0.09)	2.52 (0.36)	−2.18 (0.32)**
56	80	0.39 (0.12)	2.74 (0.29)	−2.35 (0.24)**
November 1985				
51 (LOC I)	393	0.73 (0.09)	3.40 (0.39)	−2.67 (0.32)**
51 (LOC III)	392	1.14 (0.15)	3.37 (0.38)	−2.23 (0.29)**

[a] Vertical dimension.

TABLE 3.—Spiny lobsters: mean catch per unit of effort (CPUE), standard error (SE), and mean difference in CPUE between trap types within triplets (N) consisting of rectangular-vented (R), circular-vented (C), and nonvented control (Con) traps for legal (≥ 50 mm tail width) and sublegal spiny lobsters caught during commercial escape vent trials aboard the fishing vessel Shaman. For paired t-tests, asterisks denote $P < 0.05^*$ or $P < 0.01^{**}$.

Vent size (mm)[a]			Mean CPUE			Difference in CPUE	
R	C	N	R (SE)	Con (SE)	C (SE)	R − Con (SE)	C − Con (SE)
			Legal lobsters				
43	60	457	0.96 (0.06)	1.03 (0.05)	1.03 (0.05)	−0.06 (0.07)	0.00 (0.07)
45	62	340	0.80 (0.05)	0.74 (0.05)	0.86 (0.05)	0.06 (0.06)	0.11 (0.07)
47	65	338	0.66 (0.06)	0.66 (0.05)	0.76 (0.05)	0.00 (0.08)	0.10 (0.07)
49	67	627	1.34 (0.06)	1.18 (0.05)	1.30 (0.06)	0.16 (0.07)*	0.12 (0.07)
			Sublegal lobsters				
43	60	457	0.36 (0.04)	0.46 (0.06)	0.32 (0.04)	−0.09 (0.05)	−0.14 (0.06)**
45	62	340	0.16 (0.02)	0.23 (0.04)	0.19 (0.03)	−0.07 (0.04)	−0.04 (0.04)
47	65	338	0.37 (0.04)	0.64 (0.08)	0.17 (0.03)	−0.27 (0.08)**	−0.47 (0.08)**
49	67	627	0.51 (0.04)	1.75 (0.11)	0.29 (0.02)	−1.23 (0.11)**	−1.46 (0.11)**

[a] Vertical dimension.

decreased with increasing vent size (Table 3). Significant (paired t-test, $P < 0.01$) results were obtained for the two largest vent pairs tested. The greatest mean difference in sublegal catch was attained with the 67-mm circular vent. This analysis clearly showed the increased efficiency of vented traps in releasing sublegal lobsters as vent size increased.

The mean difference in CPUE of legal slipper lobsters (≥ 56 mm TW) generally increased with vent size for the first three sizes of rectangular and circular vent pairs (Table 4; Figure 6). Traps equipped with the largest rectangular vent (49 mm) caught significantly fewer legal slipper lobsters than did adjacent control traps (paired t-test, $P < 0.01$). However, mean difference in legal slipper lobster CPUE for 67-mm circular vented traps versus control traps was not significant ($P > 0.05$). Sim-

ilar results were observed when the minimum legal size for slipper lobsters was assumed to be either 54 or 52 mm TW.

Both circular and rectangular vented traps reduced catch of sublegal slipper lobsters for the aforementioned minimum legal sizes examined. Mean differences in sublegal CPUE between vented and control traps generally increased as the size of the vent pairs increased, except for the largest rectangular (49 mm) and circular (67 mm) vent pairs. However, differences were still highly significant (paired t-test, $P < 0.01$). When these mean differences were expressed as percentages of the control CPUE, these percentages decreased with decreasing vent size (Figure 6). The 67-mm circular and 49-mm rectangular vented traps caught over 90% fewer sublegal slipper lobsters than did their respective controls. Retention of sublegal

TABLE 4.—Slipper lobsters: mean catch per unit effort (CPUE), standard error (SE), and mean difference in CPUE between trap types within triplets (N) consisting of rectangular-vented (R), circular-vented (C), and nonvented control (Con) traps for legal (≥ 56 mm tail width) and sublegal slipper lobsters caught during commercial escape vent trials aboard the fishing vessel Shaman. For paired t-tests, asterisks denote $P < 0.01^{**}$.

| Vent size (mm)[a]			Mean CPUE			Difference in CPUE	
R	C	N	R (SE)	Con (SE)	C (SE)	R − Con (SE)	C − Con (SE)
			Legal lobsters				
43	60	354	0.62 (0.05)	0.64 (0.06)	0.73 (0.06)	−0.03 (0.06)	0.08 (0.06)
45	62	486	1.84 (0.13)	1.93 (0.13)	2.06 (0.14)	−0.09 (0.11)	0.13 (0.10)
47	65	504	3.71 (0.18)	3.52 (0.19)	3.66 (0.18)	0.19 (0.14)	0.14 (0.15)
49	67	315	0.50 (0.05)	0.74 (0.08)	0.67 (0.07)	−0.24 (0.07)**	−0.07 (0.09)
			Sublegal lobsters				
43	60	354	0.29 (0.03)	0.56 (0.05)	0.45 (0.05)	−0.27 (0.05)**	−0.11 (0.06)
45	62	486	0.40 (0.03)	0.93 (0.05)	0.64 (0.05)	−0.53 (0.06)**	−0.3 (0.06)**
47	65	504	0.59 (0.05)	2.54 (0.13)	1.13 (0.07)	−1.95 (0.12)**	−1.41 (0.11)**
49	67	315	0.03 (0.01)	0.43 (0.04)	0.03 (0.01)	−0.40 (0.04)**	−0.40 (0.04)**

[a] Vertical dimension.
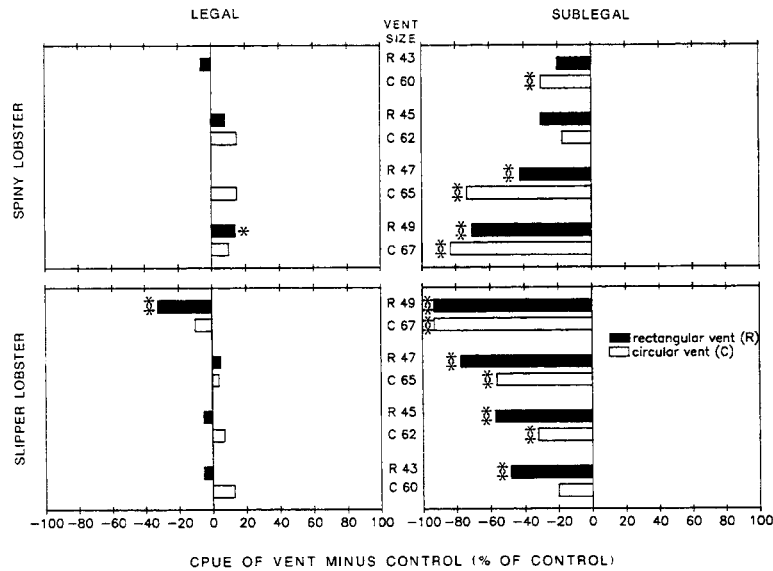
FIGURE 6.—Histograms of mean catch per unit effort (CPUE) of vented traps minus mean CPUE of control (unvented) traps, expressed as a percentage of control trap CPUE for spiny and slipper lobsters caught during commercial trials aboard the fishing vessel *Shaman*, August–November 1986. Rectangular (R) and circular (C) vent sizes are vertical dimensions (mm). For paired t-tests, asterisks denote $P < 0.05^*$ or $P < 0.01^{**}$.

lobsters was substantially less in traps with either vent type compared with the control traps (Figure 7).

Circular vents performed better than rectangular vents in maximizing combined escapement of sublegal lobsters of both species while minimizing loss of legal lobsters. To achieve sublegal escapement from rectangular traps that is 70% higher than the escapement from control traps, 49-mm rectangular vents must be used (Figure 6). This vent size also significantly reduced legal slipper lobster CPUE by 32% (paired t-test, $P < 0.01$). However, if a smaller rectangular vent was used, sublegal spiny lobster retention increased dramatically. In contrast, a 67-mm-diameter circular vent provided 83% and 93% reduction in catches of sublegal spiny and slipper lobsters, respectively, compared with those of the control traps (Figure 6). The 67-mm circular vents also allowed 10% more sublegal spiny lobsters to escape, compared with the 49-mm rectangular vents, and they reduced escapement of slipper lobsters larger than 56 mm TW (Figure 7).

Discussion

The use of escape vents substantially reduces the catch of sublegal lobsters and, compared with

traps without vents, often increases the catch of legal animals. This trend was evident for both vent designs and both species. Researchers working in other lobster fisheries throughout the world have also reported substantial reductions in retention of sublegal lobsters and increases in legal catches with vented traps (Everson 1986). In Western Australia, an area with one of the largest lobster fisheries in the world (Brown and Caputi 1983), vented traps have been used successfully since 1966. During vent trials in the Abrolhos Islands, Bowen (1963) found that traps with 57-mm rectangular vents caught at least 54% fewer sublegal rock lobsters *Panulirus cygnus*, compared with nonvented traps, while actually increasing legal catch. Similar results were reported by Ritchie (1966) and Bain (1967), prompting vent legislation for the spiny lobster fishery in New Zealand.

Escape vents have been required in lobster traps used in California since 1957. Recently, vent size was increased from 51 to 60 mm, resulting in a 75% reduction in sublegal catch and a steady increase in legal catch (K. Miller, California Department of Fish and Game, unpublished data presented at the California Cooperative Oceanic Fishery Investigation Conference, 1985). A similar situation exists in the Maine fishery for the

American lobster *Homarus americanus*. Vent experiments conducted by the Rhode Island Division of Fish and Game confirmed that vented traps reduce the catch rate of sublegal lobsters by 79% and also consistently catch more legal lobsters (Fogarty and Borden 1980). Vented traps are now required in all lobster-producing states throughout New England.

The mechanism allowing for escape of sublegal lobsters from vented traps is straightforward. Animals enter the traps to feed on bait and then leave through the vent opening once they become sated or all the bait is consumed (Ritchie 1966). More difficult to explain are observations by many researchers that vented traps often produce a greater legal catch. This phenomenon is likely due to a combination of several behavioral interactions between size-classes and species. In the New England fishery, Fogarty and Borden (1980) noted that nonvented traps often reach a saturation point that prevents additional lobsters from entering. Vented traps allow sublegal animals to escape, allowing more legal lobsters to enter. Interspecific and intraspecific competition resulting in a size-dependent hierarchy also may be a factor. Large *Jasus* spp. often drive smaller individuals from traps through the vent openings (Ritchie 1966).

The circular vent is unique in that it allows sublegal lobsters from different taxonomic families and with dramatically dissimilar body dimensions to escape in nearly equal proportions. The basis for this lies in the ability of a circular vent to select for carapace width as well as height, whereas rectangular designs merely select for height. Hence, the wider, flatter slipper lobster can escape in greater quantities than the rounder spiny lobster. Krouse (1978) also reported this phenomenon in a study of the effect of escape vent shape on catches of American lobsters and rock crabs *Cancer* spp. in the Maine fishery. He found that circular vents selected for lobsters, of similar size as those retained by rectangular vents, but also retained marketable-size crabs.

Another important consideration was the total vent area available for escapement. While testing different vent configurations in Hawaii, Paul (1984) concluded that configurations with the greatest total vent area provided the most escapement. A similar observation was made by Ritchie (1966) during vent experiments conducted aboard commercial fishing boats in New Zealand. Fogarty and Borden (1980) observed in the laboratory that lobsters located vent openings by a random process and that larger target areas were located more
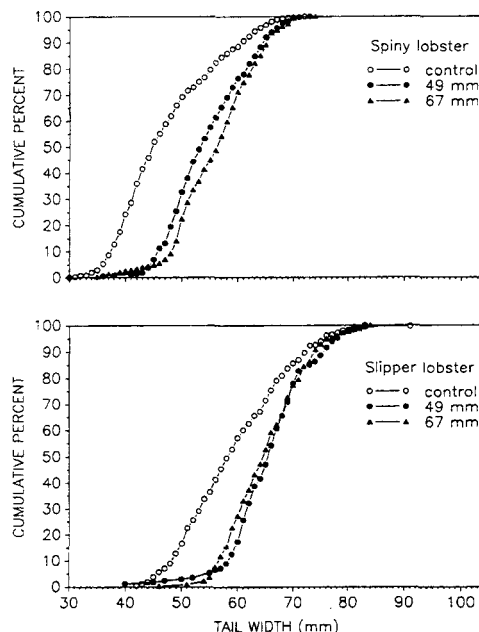

FIGURE 7.—Retention curves comparing cumulative percent caught for 67-mm circular-vented traps, 49-mm (vertical dimension) rectangular-vented traps, and control traps (unvented) for spiny and slipper lobsters caught during commercial trials aboard the fishing vessel *Shaman*, August–November 1986.

quickly and efficiently. Moreover, Brown and Caputi (1986) found that, by increasing vent height by 1 mm and doubling the number of vents per trap from one to two, they decreased retention of sublegal rock lobsters an additional 40–60% without affecting legal catch. These results and our own observations demonstrate the importance of having two vent panels, rather than one, in each trap.

Escape vents provide an inexpensive way of diminishing sublegal mortality caused by handling, which can have a major effect on future recruitment in many fisheries (Krouse and Thomas 1975; Lyons and Kennedy 1981; Brown and Caputi 1983, 1985, 1986; Hunt and Lyons 1986; J.J.P., unpublished report). Fishery-induced injuries can also significantly affect yield by slowing growth and thus delaying entry into the legal fishery (Davis 1981). Properly fitted escape vents reduce the risk of these injuries (Brown and Caputi 1983). An added benefit resulting from the use of vents is the reduction in catch-handling time (Brown and Caputi 1985).

The evidence is overwhelmingly in favor of the use of escape vents in lobster fisheries in Hawaii

and throughout the world. Because of our results, circular escape vents 67 mm in diameter have been required in all lobster traps used in the north-western Hawaiian Islands after 1 January 1988. Commercial logbook catch statistics for spiny and slipper lobsters revealed that the percentage of sublegal spiny lobsters in the catch decreased from 32% to 22% in 1987 (Clarke, unpublished data). Reduction in the sublegal spiny lobster catch was most pronounced at Necker Island (42 to 26%), which historically has produced large catches of sublegal lobsters (Figure 8). These 1988 figures amount to 32% and 38% reductions in sublegal spiny lobster catch relative to the previous year for all banks combined and for Necker Island, respectively. The observed sublegal catch was the lowest reported for the fishery since implementation of the Fishery Management Plan in 1983 (Figure 9) (Clarke, unpublished data). Total legal spiny lobster CPUE rose from 0.49 per trap-haul in 1987 to 1.05 in 1988. Following implementation of the minimum-size regulation, 25% of the slipper lobster catches were sublegal. Although there may be many reasons for apparent changes in catch composition in a fishery (J.J.P., unpublished report), these most recent commercial catch figures substantiate the effectiveness of escape vents.

The final judgment, of course, rests with the fishermen. Initial resistance has given way to popular acceptance in many of the fisheries in which vents are used (Everson 1986). During our study, the final phase of the vent experiment was conducted aboard a commercial vessel, giving the crew a firsthand experience with the effectiveness of
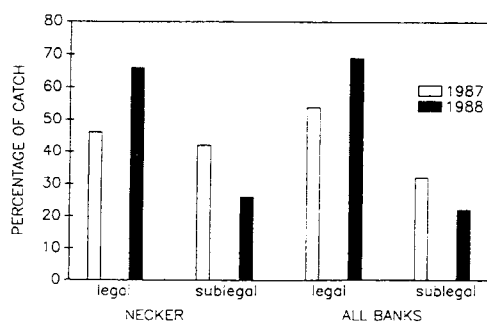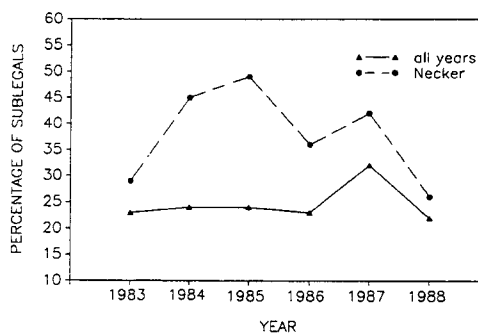

FIGURE 9.—Percentages of sublegal spiny lobsters caught by year in the northwestern Hawaiian Islands, 1983–1988, based on unpublished logbook data of R. P. Clarke, National Marine Fisheries Service.

vents. Even so, other fishermen were initially hesitant to accept the benefits of vents. Widespread acceptance did not occur until after the vent regulation became law and the first catches by vented traps were landed.

Acknowledgments

FIGURE 8.—Legal–sublegal composition (in percentages) of the commercial catch of spiny lobsters in the northwestern Hawaiian Islands, 1987–1988, based on unpublished logbook data of R. P. Clarke, National Marine Fisheries Service. Totals do not include catch of berried lobsters.

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